Harrod, B

Caving banks on the Mississippi river

CAVING BANKS

On the Mississippi River.

The Mississippi River is a succession of reverse curves. Except at or about the reversion points, there is generally a steep, caving and receding bank on the concave side, and a flat, shoaling and advancing bank on the convex side. The material from the concave bank, dropped into the swiftest current, is rapidly swept away. The convex side, is shoaler and less deeply submerged, by water more lightly charged with sediment While the extension of the point out into the channel may be as rapid as the recession of the opposite, or concave shore, its elevation to high water level is very gradual. As might be expected from this action, a comparison of surveys shows a gradual but persistent widening of the high water river. As the width increases, its mean depth diminishes. A characteristic shape of bed, resulting from this, has deeper water along either bank, and a middle ground, or bar area, at the intermediate node or reversion point between bends. This is the origin of many islands. The absence of defined channels across this bar area, from one pool to another, is the obstruction to low water navigation. The development of channels through it is the result of the increase of local velocity, by the reduction of sectional area as the water falls. If these channels are numerous, as frequently occurs, they are tortuous, uncertain, and of less depth.

"These bars are not permanent in position; on the contrary, they are prone to shift as the bends become more acute, extend, or move downward. Indeed, under the general rule that the bars form at the reversion point of curves, it is evident that their position must vary as these curves vary, and that the holding of the curves, by revetment or otherwise, is an essentially early step in the control of the river. It antedates logically the retrenchment which is to deepen the water at the bars." *

From caving banks is derived a large part of the material of which bars are composed. The banks are generally of sand and clay, seldom purely of either material, but mixed in different proportions according to the conditions under which they were built. The finer and lighter parts float long distances with low velocity, and are deposited in quiet water, under the shelter of willow points. The sediment from the Mississippi is so light that at times, 1200 miles below its mouth, at medium and low stages, and correspondingly small velocities, not only the charge of sediment per unit of measure, but even the total quantity afloat, is greater than at times of flood from the Ohio, when the discharge and velocity are largely increased.

*Prof. H. Mitchell—App. M. R. C. Rep. 1882, p. 263.

The more important part, however, the sand and fine gravel, sinks rapidly, forming a loose and shifting bed, which is shaped into sand-waves and bars by the forces of the river, constantly changing in direction and intensity. If it falls in a pool, where the scouring power of the higher stages is concentrated, the next flood sweeps it down to the bars in the wider sections below, where the current spreads, and its transporting power abates. From this halting place, where the current becomes relatively greater, as lower stages prevail, it is scoured down to the comparatively still pool below. The range of elevation of these bars, during the annual oscillations of the river, frequently exceeds the depths found on them at low water. A high water survey, reduced to low water gauge readings would exhibit numerous dry bars extending across the bed. The more important down stream movement of sediment, is, therefore, intermittent, and it can be understood that the same material may enter successively into the composition of each bar as it moves, by semi-annual excursions, towards the sea.

The extreme variations of width now existing in the river, with a tendency towards further increase, are not normal, but exaggerated by caving. The physical history of the river is not one of growth from a narrow to a wide stream, but of the retrenchment of a wider expanse of surface to a confined and limited waterway, of an estuary to a river. The bed still strives to conform its dimensions to the smallest section that will contain the volume of discharge, and to a shape that will offer least resistance. The opposite tendency which is now observed marks, by disturbed regimen, the presence and control of abnormal influences. It is therefore just to expect that, if the elongation of points, and the growth of middle bars were resisted by permanent banks, the material now causing their extension towards the retreating shore, would be deposited over areas outside of the required bed limits, so as to raise them to bank level, and thus, by narrowing the width restore conditions more favorable both for navigation and discharge. The obvious illustrations of this are the exceedingly narrow and deep sections along the bluffs at Columbus, Fulton, Randolph, Memphis, the old Vicksburg and Grand Gulf channels, and the other bluffs below.

While this description is generally true of the character of the changes taking place throughout the River, it should be understood that the parts where the results have been disastrous, or the danger is imminent, are, in the main, localized and confined to certain reaches where navigation is impaired, or large interests are menaced. While in a sense it is true as to all parts of the river, it is not, in such sense as to require the revetment of all of them.

There is fair agreement among engineers as to the causes now impairing the navigation and discharge capacity of the river. The importance of contracting the lake-like expansions at parts of its course, and of such works as will promote uniformity of section and velocity is generally acknowledged. There are, however, different opinions as to the means of reaching this result. There is a contention whether the direct application of protective work to a caving bank is necessary to hold it, or whether its caving can be indirectly, or incidentally checked by

the uniformity of section, velocity and sediment in suspension which, it is claimed, will result from such works of contraction as will give ease and safety to navigation, and prevent destructive floods. On the one hand it is maintained that the adjustment between the velocity and the charge of sediment carried by each unit of discharge is so close, that were the section and velocity uniform, the water would always have a load of sediment proportioned to that velocity, and would pass through its channel without loss or gain of solid matter—or, without erosion of its banks. It will be observed that this hypothesis excludes the effect of impact in destroying the banks. It is held, on the other hand, that, while velocity and the degree of saturation with sediment are related yet it is and always will be necessary to protect the banks, to a greater or less extent, in order to hold the contraction obtained by dikes projecting in the channel, to prevent the destruction of this dike work by changes in the River above, and to check the deterioration of reaches which are now in satisfactory condition.

I shall give the first of these views as presented by its most distinguished advocate, Capt. Jas. B. Eads:

"The Mississippi is simply a transporter of solid matter to the sea. "This consists chiefly of sand and alluvion, which is held in suspense by "the mechanical effect of the current. A small portion, consisting of "larger aggregations, such as gravel, boulders, small lumps of clay, and "drift-wood, is rolled forward along the bottom. By far the greater "portion is, however, transported in suspension. The amount of this "matter, and the size and weight of the particles which the stream is "enable to hold up and carry forward, depend wholly upon the rapidity "of the stream, modified, however, by its depth. The banks and bottom "being chiefly sand and alluvion, are easily disintegrated by the move-"ment of the waters, hence the amount of load lost by any slackening of "the current at one place, will be quickly recovered in the first place "below where the current is again increased.

"The popular theory advanced in many standard works on hydraulics, "to-wit: that the erosion of the banks and bottom of streams like the "Mississippi is due to the friction or impingement of the current against "them, has served to embarrass the solution of the very simple phenom-"ena presented in the formation of the delta of the Mississippi, because "it does not explain why it is, that under certain conditions of the water "it may develop with a gentle current an abrading power, which, under "other conditions, a great velocity cannot exert at all. A certain velocity "gives to the stream the ability of holding in suspense a proportionate "quantity of solid matter, and when it is thus charged it can sustain no "more, and hence will carry off no more, and therefore cannot then wear "away its bottom or banks, no matter how directly the current may "impinge against them.

"In the upper portions of the delta (which, according to some writers "extends a few miles above Cairo), the width of the river is very irregu-"lar. When a rise occurs, the current is increased in the narrow parts of "the river, and the carrying capacity of the stream consequently becomes "greater and it at once takes up an additional load. When, however, as

"the stream flows on, it enters a wide expanse, the current is slackened "and the excess of load is dropped to the bottom, and thus shoals or bars "are formed. From such expansion of channel way, the volume of water, "thus relieved of a portion of its load, passes into another one of the "narrow parts of the channel, and here its current by contraction is "again accelerated, and the increased load which it can carry is immedi- "ately scoured up from the bottom and sides of the channel. In the "bends, the centrifugal force of the water makes the current more rapid "on the cancave bank of the stream, and there it usually gets its addi- "tional load, and the caving in of the bend testifies to the rapacity of the "water at that point of its course. Once loaded, however, it can carry "no more, and hence it may sweep around half a score of other bends "below with equal velocity, without injury to them. If it encounter "another expanse, however, it again loses part of its velocity, and with "it, part of its load, to be recovered again in the narrow parts of its chan- "nel below. It is evident, therefore, that if the channel were at all "uniform in size, the current would be more constant, and the alternate "depositing and recovery of part of the burden of the stream would be "prevented. This loading and unloading is synonymous with caving "banks and sand bars.

"The lower part of the river, nearly all the way from Red River to the "mouths of the passes, is remarkably uniform in width, and is therefore "comparatively free from falling banks and shoals. This part of the river "is transporting its load with great regularity, and without interruption, "to the sea; whilst that above, owing to the alternating contractions "and expansions in its channel, transports its burden with great irregu- "larity, dropping a part here and taking up a part there, and thus by "successive stages, from season to season, it is borne forward." *

"If the quantity of suspended sediment is regulated by the current "and if the bed of the river is formed of its own sedimentary deposits "instead of this unyielding and marble-like clay, then it is entirely prac- "ticable to lower its flood-line or slope and deepen its channel by simply "constructing light willow or brush dams during low water on the shoals "which are then dry, or nearly so, at the various wide places in the river "where the bars always exist. These dams would cause the deposit of "more sediment on the shoals by checking the current, and would deepen "the contracted channels that would remain by increasing the current in "them. In this way the high water channel would be brought to a com- "parative uniformity of width by gradually encouraging, from year to "year, the deposition of sediment over the wide expanses, and this uni- "formity of depth, would practically stop the caving of the banks." †

"I declared that the revetment of caving banks would be enormously "expensive and wholly unnecessary, and I desire now to repeat that I "never have sanctioned the revetment of the banks, because of its enor- "mous expense, and because I am sure it is wholly unnecessary before the "rectification of the high water channel. I believe that no real succes- "can ever be achieved unless the principle of contracting the high wate

* Mississippi Jetties, 29, 30, 31. Corthell, pp. 29, 30, 31.

† Letter to President of Miss. Riv. Com. Jan. 20, 1886.

"channel be constantly adhered to, and all other works be made simply "auxiliary and subsequent thereto, and be regarded as only of secondary "importance." *

These extracts present clearly and eloquently this attractive theory. It would be greedily accepted, if it agreed with observations, or explained phenomena. Unfortunately, it does neither.

Those who reject this hypothesis contend that the law governing the relation of velocity to sediment in suspension is modified by active but obscure conditions, as is proved by all observations on the Mississippi River; and, that its practical results are not apparent in the surveys of the River, or the works for its improvement.

I submit, in tabulated form, the results of every set of velocity and sediment observations ever, to my knowledge, made between Cairo and the head of the Passes. The velocities, except in one table, are graded in the first column, and the discordant sediment results placed in the last. In the exceptional case (Carröllton, 1851-'52) this order is reversed, and the amount of sediment is graded in the first column, and the accompanying velocities transferred to the last. The sixth table is constructed from the other five:

Of the observations furnishing data for these tables, those at Carrollton in 1851—52 and at Columbus in 1858 were made by Humphreys and Abbot; those at Columbus, in 1879, by what was styled the Low Water Board of that year, and those at Fulton and Carrollton, 1879—80, by the Mississippi River Commission.

These tables show clearly that, while the same velocity may be maintained for some time, or may recur many times during the observations, it is not necessarily accompanied by similar and proportionate charges of sediment. The relation is disturbed and largely controlled by causes other than velocity and depth, among which the tributary contributing most to the discharge, and the character of the bed, may be assigned important parts.

That the irregularities, or departures from a fixed charge of sediment, per unit of measure, for certain velocities, which appear throughout the tables, are only modifications of the law resulting from differences in the depth of the river is not apparent, and, to say the least, requires further investigation before it can be accepted as a scientific and satisfactory explanation.

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* Letter to President Miss. Riv. Com. Jan. 1886.

VELOCITY AND SEDIMENT OBSERVATIONS

I. CARROLLTON, 1851–'52.

Weekly Average of grams in 600 grams of water.	Velocity in feet per second during week.	Weekly Average of grams in 600 grams of water.	Velocity in feet per second during week.
.094	1.42–1 80	.276	5.55
.094	1.88	.282	1.82
.097	2.55	.308	3.26 to 4.66
.121	1.51	.344	6.06 to 6.22
		.350	3.41—4.16
.131	3.77—3.89	.369	2.36—2.52
.139	1.75—1.79	.414	2.90—3.02
.141	3.66—4.01	.442	5.[illegible]6—6.13
.142	1.64—1.66	.443	4.51—4 58
.148	1.58—1.60	.459	4.79
.151	1.70—1.75	.469	4.76—4.79
.165	1.64—1.83	.474	3.15—3.30
.169	3.87—4.50	.475	4.13—4.38
.184	2.14	.510	2.99
.184	2.03	.513	3.25
.187	4.69– 4.75	.521	3.36—3.42
.192	2.28	.539	4.23—4 34
.197	1.60—1 74	.591	3.87—4.37
.199	1.69	.594	5 60—5.82
.204	1.99	.599	4 70—4.78
.205	4 64—5 64	.614	5.04—5.57
.212	4.90—5 10	.627	4.53—4.85
.228	1.93	.643	4.82
.241	5.94—5 99	.692	3 64—3.66
.255	5 90—607	.918	4.33 to 4.47
.266	1 94—2.18		

II. CARROLLTON, 1879–'80.

Mean velocity in feet per second.	Periods of observation.	No. of observations in each period.	Extreme range of observations.	Average milligrams of sedim'nt in 500 cubic centimetres of water.
1½ to 2	1	1		145
	2	2	125 to 170	142
2 to 2½	1	3	245 to 375	312
	2	2		190
2½ to 3	1	2	390 to 500	445
	2	1		265
3 to 3½	1	1		400
	2	1		330
	3	1		470
3½ to 4	1	2	270 to 285	277
	2	2	335 to 380	357
	3	1		575
4 to 4½	1	1		670
	2	1		230
	3	2	510 to 540	525
4½ to 5	1	1		310
	2	1		210
5 to 5½	1	1		535
	2	1		215
5½ to 6	1	2	370 to 385	377

III. COLUMBUS, 1858.

Mean velocity in ft. per sec'd.	Periods of Observation.	No. of Obsrva'n in each period.	Range of Observations during Period.	Average No. of Grams Troy per cubic ft. of water
1½ to 2	1	22	44 to 221	130
2 " 2½	1	9	163 to 472	260
	2	8	125 to 258	188
	3	1		354
2½ to 3	1	4	546 to 708	638
	2	1		281
3 to 3½	1	5	422 to 598	535
	2	1		502
3½ to 4	1	7	465 to 664	619
	2	3	280 to 391	325
	3	5	383 to 628	502
	4	3	317 to 374	347
4 to 4½	1	2	605 to 641	623
	2	2	406 to 738	572
	3	2	140 to 266	203
	4	3	354 to 478	418
4½ to 5	1	1		269
	2	1		269
	3	2	524 to 531	527
	4	5	332 to 797	564
5 to 5½	1	1		316
	2	1		280
	3	1		635
5½ to 6	1	2	235 to 279	257
	2	1		539
6 to 6½	1	1		490
6½ to 7	1	1		269
	2	1		288
	3	5	147 to 294	204
	4	1		199
7 to 7½	1	5	211 to 307	285
	2	2	470 to 538	504
	3	1		278
	4	5	235 to 382	307
	5	1		155
7½ to 8	1	1		258
8 to 8½	1	1		355
	2	1		223

IV. COLUMBUS, 1879.

Mean velocity in feet per second.	Periods of observation.	No. of observations in each period.	Range of observation during each period.	Av. No. grams per cub. foot of water.
2 to 2½	1	3	22 to 37	29
2½ to 3	1	17	20 to 65	41
	2	4	27 to 29	28
3 to 3½	1	25	29 to 111	56
3½ to 4	1	1		5
	2	1		6
	3	2		146
4 to 4½	1	5	5 to 7	6
	2	2	22 to 27	24
4½ to 5	1	2	10 to 35	42
	2	5	27 to 55	37
5 to ½	1	2	11 to 12	11
	2	2	42 to 48	45

V. FULTON, 1879-'80.

Mean Velocity in ft. per secn'd	Periods of Observations.	No. of Ob'ns in each Period.	Range of Observations during each Period.	Average No. of Millegrams of Sediment in 500 Cubic Centim.
2 to 2½	1	8	250 to 390	298
	2	14	300 to 470	354
2½ to 3	1	12	340 to 570	452
	2	5	270 to 388	318
	3	5	400 to 460	428
3 to 3½	1	4	240 to 450	317
	2	5	430 to 810	605
	3	8	450 to 630	517
3½ to 4	1	9	230 to 325	274
	2	4	670 to 845	734
4 to 4½	1	2	190 to 230	210
	2	8	355 to 445	407
	3	1	255 to 295	272
	4	13	440 to 620	521
	5	2	765 to 790	777
4½ to 5	1	2	250 to 260	255
	2	2		450
	3	4	400 to 450	426
	4	6	580 to 950	781
	5	4	565 to 920	776
5 to 5½	1	1		555
	2	1		388
	3	2	850 to 880	865
	4	2	925 to 935	930
5½ to 6	1	1		235
	2	8	350 to 690	279
	3	2	340 to 380	360
	4	2	830 to 960	895
	5	4	755 to 870	826
6 to 6½	1	2	335 to 370	352
	2	1		195
	3	6	205 to 385	312
	4	1		375
	5	2		270
	6	5	830 to 1160	993
6½ to 7	1	1		920
	2	1		385
	3	1		170
	4	4	330 to 1010	562
7 to 7½	1	5	255 to 545	390
	2	4	315 to 705	496
	3	1		135
7½ to 8	1	1		145

VI. CARROLLTON, 1851'–52.

Date.	Gauge.	Discharge cubic feet per second	Velocity, feet per second.	Prop. of sediment by wt.	Total lbs. of sediment.
January 21	5.	482,392	3.	$\frac{1}{1177}$	25,616
3d Week June	11.6	779,384	4.40	$\frac{1}{654}$	74,482
April 1	15.25	1,112,559	5.96	$\frac{1}{2490}$	27,924
COLUMBUS, 1858.					
August 30	13.	267,700	2.55	$\frac{1}{619}$	27,027
July 22	23.7	596,350	4.64	$\frac{1}{549}$	67,899
June 28	38.	1,156.960	7.23	$\frac{1}{2823}$	25,618
June 14	39.8	1,318,733	8.04	$\frac{1}{1354}$	60.850
COLUMBUS, 1879.					
July 2	23.4	410,000	3.75	$\frac{1}{195}$	131,835
April 5	33.65	720.000	5.20	$\frac{1}{2489}$	18,078
FULTON, 1879–'80.					
July 31	168.25	340,000	3.5	$\frac{1}{610}$	34,836
March 28	188.	1,070,000	7.75	$\frac{1}{3453}$	19,367
CARROLLTON, 1879–'80.					
August 19	2.	315,000	2.36	$\frac{1}{1333}$	14,769
August 9	4.40	425,000	2.93	$\frac{1}{1111}$	23,909
May 19	13.40	850,000	5 34	$\frac{1}{2305}$	23,047

The following table is compiled from comparative surveys, by the Mississippi River Commission, of the bank line of the river from Cairo to Memphis. It further shows that the amount of caving of banks is not dependent upon the degree to which the water flowing against them is charged with sediment. The demarkation between the muddy discharge from the Mississippi and the clear water from the Ohio is frequently observable, by the eye, for twenty or thirty miles below their junction, and, by the sediment trap, for two or three hundred. Notwithstanding this, the caving on the Right bank, washed by water more heavily charged with sediment, exceeds that of the Left bank, along which flows, with equal velocity, the comparatively clear discharge of the Ohio.

COMPARATIVE CAVING ON RIGHT AND LEFT BANKS.

RIGHT BANK.

Location.	LINEAR FEET.		AREA IN SQ. FEET.	
	Each.	Aggregate	Each.	Aggregate.
Lucas	35,000		9,310,000	
Beckwith	20,600	55,600	10,526,600	19,836,600
Isld 8	23,300	78,900	3,961,000	23,797,600
Phillips	30,000	108,900	4,800,000	28,597,600
Lafaye	7,000	115,900	1,750,000	30,347,600
New Madrid	31,300	147,200	11,800,000	42,147,600
Ruddles'	28,750	175,950	10,235,000	52,382,600
L. Prairie	25,000	200,950	18,775,000	71,157,600
L. Cypress	22,700	223,650	15,218,000	86,375,600
Coleman	28,100	251,750	9,469,700	95,845,300
Barfield	37,600	289,350	13,912,000	109,757,300
Canadian River	16,000	305,350	15,968,000	125,725,300
Fletcher	16,000	321,350	6,080,000	131,805,300
Craighead	11,000	332,350	3,168,000	134,973,300
Morgan	11,000	343,350	5,511,000	140,484,300
Idaho	54,300	397,650	18,506,300	159,000,600
Bradley	13,300	410,950	3,152,000	162,152,600
Hopefield	11,700	422,650	9,594,000	171,746,600

LEFT BANK.

Location.	LINEAR FEET.		AREA IN SQ. FEET.	
	Each.	Aggregate	Each.	Aggregate.
Puntney	20,000		7,000,000	
Columbus	5,000	25,000	600,000	7,600,000
Wolf Isld	20,500	45,500	2,870,000	10,470,000
Hickman	11,000	56,500	1,628,000	12,098,000
French's	18,000	74,500	1,980,000	14,098,000
Shotwell	5,000	79,500	250,000	14,348,000
Missouri Point	20,000	99,500	10,040,000	24,388,000
Noland's	10,300	109,800	7,014,300	31,402,300
Darnell	15,000	124,800	16,275,000	47,677,300
Meriwether	28,000	152,800	10,388,000	58,065,300
Reelfoot	50,200	203,000	12,901,400	70,966,700
Booth's	15,000	218,000	2,400,000	73,366,700
Needham	33,300	251,300	13,153,500	86,520,200
Forked Deer	33,000	284,300	28,446,000	114,966,200
Ashport	19,000	303,300	6,536,000	121,502,200
Idaho	20,000	323,300	9,000,000	130,502,200
Bateman	26,000	349,300	14,014,000	144,516,200
Beef Isld	11,000	360,300	5,258,000	149,774,200
Redman	16,000	376,300	4,960,000	154,734,200

Between Cairo and Memphis the bluffs, composed of less erosible materials, are tangent to four of the concave bends of the Left bank. If, however, these bends are omitted, and averages of the length and area of caving in the other bends of the two banks compared, the excess will still be found on the Right, or muddy water shore.

The assumptions, therefore, that in the Mississippi river, the amount of sediment carried in suspension is directly determined by the velocity, and that the banks only cave when the water flowing against them has an undercharge of sediment for its velocity, are not sustained by observation or experience.

The suspension of sediment is an indirect result of velocity, depending more closely upon the character of the bed—its symetry, smoothness and straightness—than upon the velocity, or the relative depth of its different reaches and stages. Grains of sediment have no power of movement independent of the medium surrounding them; and friction alone against a smooth bed could not impart the vertical movement to water necessary to lift them. The conditions prevailing in large natural stream beds are necessary for a great suspension of sediment.

The projections, inequalities and sinuosities of such beds expose the material composing them to the impact or impingement of the current rather rather than to simple friction, and cause those indirect movements of large masses of water which, in great rivers, develop whirls, boils and eddies, and which alone are capable of lifting numerous and coarse grains of silt, sand and gravel. When a boil rises in the Mississippi river, the surface may be lifted many inches, and the charge of sediment is so dense, that it is seen to roll away from the crater in cloud-shaped masses. Mr. Clemens Hershel, in his paper on the "Erosive and Abrading Power of Water," justly says: "That direct friction tends to drag materials along the bed, or down the banks, if they have a sufficiently steep side-slope," and that "The effect of the simple friction of a stream upon its bed or banks is not a source of danger; its action is very slow, and it has never been shown to be of a dangerous character in any instance."

Besides these general causes effecting the amount of sediment in suspension, it is largely dependent upon the tributary from which the main trunk is receiving most of its discharge. If this is from the Missouri, the sediment is great at any stage. If from the Ohio, the amount may be comparatively small, even at high stages.. Capt. M. R. Brown, U. S. Engineer, a most careful observer, in the 8th Report on the South Pass Jetties, p. 32, states: "It is also apparent that great variations are "found in the ratio of sediment and of sand to water through periods "characterized by little or no change in the stages of the river at New "Orleans. The affluent which contributes most powerfully to a rise in "the river at New Orleans, undoubtedly determines, to an important "extent, the amount and character of the sediment passing the jetties' "ends, and therefore, the advance of the 20 feet curve, and the difficulty "encountered in an effort to keep the channel open."

This hypothesis, claiming a direct and exact relation between the sediment in suspension and the velocity of the stream, and ignoring the effect of the impact of the mass of water in eroding the banks, is unsupported by theory and experience, as well as by the careful, scientific observation heretofore cited. If the predicated high water contraction had been

applied, giving uniform width and velocity, and in consequence, caving had been checked, we should then have less sediment, by the amount now contributed by caving banks, and also greater velocity, because it would be relieved from the work of suspending and transporting that amount of sediment. Under these conditions, why should not erosion, if the theory first prevented is true, be increased, rather than diminished?

Again, uniformity of section affects only mean velocity. The extremes would still vary greatly, along the bank, as it is concave or convex. Fill and scour of the bank would therefore continue.

From experience, it is known that, to induce a deposit up to the level of high water, by contraction works, requires several years. Also, from experience and the terms of the theory, caving will not cease until high water contraction is complete. During this period of bank development caving will therefore continue on the concave side, and the line of the new convex shore and the contraction works defining it, must be annually advanced at an equal rate. If they are not, by the time complete results are obtained on the original line, the river will have recovered the width that first made contraction necessary. If the line is annually advanced the cost of contraction will largely exceed that of bank protection before permanent results are secured.

It is essential, for the success of this theory that its application should be complete. While a depth of 15 feet at low water will give ease and safety navigation by the present river fleet, the contraction works that suffice to give this depth have no effect in arresting the caving in reaches where they have been constructed. Were the depth of thirty feet, now found through the jetties, extended up the river, in low water, to Cairo, it would not give the uniformity of section and velocity upon which the success of this theory is predicated. Should that depth be obtained, the fullest demands of commerce would be satisfied, but the work must still be prosecuted, to the end of arresting the caving. Under this aspect the exclusive use of contraction work isof much greater proportions, time and cost, than the direct application of protection work to caving banks.

To conclude—the protection of caving banks, while not a "a system" or "plan" in itself, is part of any rational system of river improvement. Neither jetties, nor levees, nor revetment, nor contraction work constitutes a system, of itself, any more than does a dose of rhubarb, or ginger, or calomel, or quinine constitute a system of medical practice. They are all founded on the same principle, and their combined use is the system of improvement of alluvial rivers. There is no better jetty, than a well reveted bank. There is no more practical contraction than holding a bank that is receding from your dike work at the rate of one hundred feet a month. Nothing so simplifies and reduces the levee problem as a permanent location; and, when the bank resists, the bed must yield to erosion. From these considerations follows the proper use of bank revetment, as an essential part of river improvement, in connection with contraction by permeable spurs and dikes, on reaches that are undergoing general improvement, as at Plum Point and Lake Providence; also where great commercial interest are in jeopardy, as in harbors and

along city fronts ; and also to avert such changes in the river as will impair its navigation, or are at variance with the theory and plans upon which the improvement is being conducted, such as cut-offs, or the deflection of any large part of its volume.

Any intention of a more extended or exclusive use of this feature of the work, such as its application to all bends, regardless of their influence and condition, or the abandonment of contraction by permeable dikes, in the many places where such work has an advantage, is absolutely disclaimed.

The plan for the improvement of the Mississippi River proposes to control the flood discharge and the direction of its currents at all stages, to secure, by its own forces, a capacious and unobstructed bed.

In it, all the various devices and constructions which will " correct, permanently locate and deepen its channel, and protect its banks " are included. No arbitrary preference or discrimination in methods has been contemplated, under the conviction that all the resources of the science of Hydraulic Engineering will be required for the accomplishment of the great work.

It is charged that the Mississippi River Commission has been derelict, in failing to "deflect the waters of the Red River from the Atchafalaya into the Mississippi." Concerning this subject, I desire to make the following statement:

In the Report of Dec. 21, 1883, p. 15, it is declared that "the Commission is as mindful of the importance of this part of their work as of its difficulties. Upon the completion of surverys and examinations now in progress, full report and recommendations will be made." In the estimate accompanying this report an appropriation to repeat the work of dredging, to maintain low water navigation through the mouth of Red River was recommended (p. 14). But as a plan for permanent improvement had not been matured, no appropriation therefor was then advised. The Congress to which this report was submitted (48th. 1st sess.) appropriated for the Mississippi, $3,000,000, the amount estimated for specified work, exclusive of New Madrid and Memphis reaches. But the act of appropriation recited, among the objects of expenditure, the "Deflection of the water of Red River from the Atchafalaya into the Mississippi.'' As no estimate had been submitted in the report for this special work, it could only have been undertaken by omitting some other work recommended and for which appropriation had been asked and made. Also, the Commission believed that the deflection of the discharge of Red River into the Mississippi involved danger of increased overflow on the latter stream, of which it was necessary to give warning, and for which preparation was necessary in the raising of the levees below Red River. Therefore, it was deemed wise by the Commission, under its advisory functions, to postpone action until full discussion and recommendations could be presented to Congress. This was done, at the subsequent session, in the Report of Dec. 19, 1884, pp. 20–28. As that Congress (48th, 2nd sess.) passed no River and Harbor Bill, the Commission was unable to carry out its intention of immediately commencing the plan submitted therein.

These recommendations of the Report of 1884 have not been withdrawn or modified. On the contrary, they are renewed in the report submitted to the present session. It is fair to presume that, had appropriations been made for the current fiscal year, the work would now have been well advanced; and that, should the present Congress make the necessary appropriation, it will be undertaken; as soon as possible.

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